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Bare Pomeron in Inclusive Processes

A. K. Likhoded[†], N. V. Mokhov[†], and O. P. Yushenko[†]
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

[†] *Permanent address:*
Institute for High Energy Physics
Serpukhov, U. S. S. R.

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1 Introduction

It is well known that the phenomenon of increasing total cross sections has an explanation in the framework of Regge theory with the supercritical Pomeron[1]. The amplitude for elastic hadron-hadron scattering is given in the theory by the sum of reggeon diagrams. The first term of this eikonal series corresponds to the "bare Pomeron" contribution

$$A_{22}(s,t) = (i - \cot \frac{\pi\alpha(t)}{2}) s^{\alpha(t)} \gamma(t), \tag{1}$$

where $\alpha(t) = 1 + \Delta + \alpha' t$. This amplitude is used usually as an input to the eikonal approach, which gives a correct unitary description.

Theoretical support for $\Delta > 0$ lies in perturbative QCD calculations. The perturbative QCD Pomeron was found[2] to be a series of poles in the complex angular momentum plane at

$$1 \leq j \leq 1 + \Delta \tag{2}$$

with the upper limit $\Delta < 4 \ln 2\alpha_s(t)/\pi$ [3]. For $\alpha_s = 0.2 - 0.25$ this gives a rather large value $\Delta = 0.55 - 0.65$.

Another way to get an indication of the value of Δ is the QCD calculation of the deep inelastic cross section[4]. The small$-x$ behavior of parton distribution functions has an easy explanation in Regge theory. The limit $x_{bj} \to 0$ is the exact Regge asymptotic behavior for the amplitude of elastic Compton scattering. In the framework of the leading logarithm approximation

$$f \sim \frac{1}{x} \exp\left(\sqrt{\frac{48}{11 - 2n_f} \ln(1/x) \ln\ln \frac{Q^2}{\lambda^2}}\right). \tag{3}$$

One can find an effective power law defined by $\Delta = \partial \ln f / \partial(1/x) - 1$. This gives $\Delta = 0.23$ for $Q^2 = 16 GeV^2$ and $\Delta = 0.5$ for $Q^2 = 400 GeV^2$. Unfortunately, because of the absence of data on deep inelastic scattering (DIS) in the small$-x$ region ($x < 0.05$) one can not extract the bare Pomeron parameters from there.

The analysis of data on the total cross section performed by the various groups gives quite different values of Δ. In the earlier papers of the Orsay[5] and ITEP[6] groups the value $\Delta \sim 0.13$ has been found. The two-pole approximation for the bare Pomeron gives the interval $0.09 \leq \Delta \leq 0.3$ [7], as providing a pretty good description of σ_{tot}. The value $\Delta = 0.3$ agrees with cosmic ray data. Two recent works using an analysis of σ_{tot} and of *Re/Im* give very different values $\Delta = 0.56$ [8] and $\Delta = 0.11$ [9].

2 Leading Pomeron singularity form

Another way to determine the bare Pomeron parameters is to fit the data on inclusive particle production in the central region. The main argument in support of such a method is the AGK cancellation of cut contributions in the central region[10]. In that region one has deal with the first term only — the double bare Pomeron diagram (Fig.1). In the high energy limit

$$\frac{d\sigma}{dy}|_{y=0} \sim s^{\Delta}. \tag{4}$$

Such a behavior is true only if the three-Pomeron vertex r_{PPP} is small. The present data on diffraction dissociation give $r_{PPP} \sim 0.1$ and below its contribution will be neglected.

Formula (4) describes the leading term only and does not take into account the contribution of secondary trajectories. At moderate energies $\sqrt{s} < 100 GeV$ the rise of particle density in the central region is connected with the vanishing of the secondary reggeons in the Mueller-Kanchely diagrams[11,12] (see Fig.1). At the highest energies the secondary contributions are negligible and the rise can be connected with the leading Pomeron singularity only.

A preliminary analysis[13] of the data on $d\sigma/dy$ at $y = 0$ shows power dependence of the cross section with the exponent $\Delta \simeq 0.17$. It was shown there that at low and moderate energies the non-asymptotic contribution of secondary reggeons exists and that it is very important. However, the values of the parameters (PP, RP and RR) which have been found in[13] can not describe the inclusive spectra at non-zero values of rapidity. This arises from the positivity of the RP-parameter which produces the y-behavior of inclusive spectra. On the other hand it is known that with $\alpha_P = 1$ and a negative RP-parameter one can get a good description of the data in wide energy and rapidity intervals[14].

One can solve the difficulty by introducing a more complex form for the leading Pomeron singularity. There is a theoretical basis for such complexity[2]: the series of poles at $\alpha > 1$. So, the simplest assumption is that the leading Pomeron singularity can be considered as a couple of poles at $\alpha_F = 1 + \Delta$ and α_P. Such an assumption has been used already for the total cross section analysis[7].

We re-fitted below the total cross sections and elastic slopes at small t to fix the coupling constants of F, P and R with hadrons. Substituting these constants into the double-reggeon diagram (DRD) approximation for the inclusive cross section one can get a wonderful description of the various data.

3 Double-reggeon representation

It is known that the generalized optical theorem[11,12] and factorization of leading singularities give an expression for the inclusive cross section of the reaction $a + b \to cX$ in the central region

$$E\frac{d^3\sigma}{d^3p} = \frac{1}{s}\sum f_{ij}|\frac{t}{m_T}|^{\alpha_i(0)}|\frac{u}{m_T}|^{\alpha_j(0)}, \tag{5}$$

where $i,j = 1,3$; $t = (p_a - p_c)^2 \simeq -\sqrt{s}m_T e^{-y}$; $u = (p_b - p_c)^2 \simeq -\sqrt{s}m_T e^{y}$; $s = (p_a + p_b)^2$; $m_T = \sqrt{m_c^2 + p_T^2}$; $y = \ln((p_c + E_c)/m_T)$.
Here, the dependence on the transverse mass is absorbed into the constants f_{ij}. Integrating over p_T one finds

$$\frac{d\sigma}{dy} = \frac{1}{s}\sum f_{ij}(\sqrt{s}e^{-y})^{\alpha_i(0)}(\sqrt{s}e^{y})^{\alpha_j(0)} \tag{6}$$

The summation in (6) is over three reggeon singularities: a froissaron with $\Delta > 0$, a Pomeron with $\Delta = 0$ and a reggeon with $\alpha = 0.5$. The constants are given by $f_{ij} = G_i A_{ij} G_j$, where G_i is a coupling constant for the singularity of type i with a proton or antiproton (for secondary reggeons these constants are not identical), A_{ij} is the central vertex in Fig.1.

Let us note that simultaneous analysis of data on the reactions $p + p \to c^- X$ and $\bar{p} + p \to c^- X$, where c^- is a negatively charged particle, in a wide energy interval is consistent with the above factorization because of the presence of ten different DRD for ten constants: $G_F, G_P, G_{RP}, \bar{G}_{RP}$, $A_{FF}, A_{FP}, A_{FR}, A_{PP}, A_{PR}, A_{RR}$.

4 Coupling constants

It was already mentioned above that the connection with the elastic amplitude imposes some limitations on the constants G_F and G_P because these constants control the asymptotic behavior of the total cross section. So, it may be convenient to fix these parameters from analysis of the elastic amplitude and to determine others from inclusive spectra.

We use the eikonal representation for the elastic amplitude

$$A(s,t) = i\int(1 - e^{i\Omega})J_0(b\sqrt{-t})bdb, \tag{7}$$

where Ω is the eikonal function consisting of three components $\Omega = \Omega_F + \Omega_P + \Omega_R$. Each part is a Fourier transform in b-space of the usual pole expression

$$A_i(s,t) = s^{-1} G_i^2 (s e^{i\pi/2})^{1+\Delta_i+\alpha_i' t} e^{b_i t} \quad (8)$$

The simultaneous fit of data on the total cross sections and elastic slopes (b_i) for $pp-$ and $\bar{p}p-$ scatterings allows the determination of the parameters of interest. We use the following data $\sigma_{tot}(pp)$ [15-29], $\sigma_{tot}(\bar{p}p)$ [15,16,19,20,30-33], $b(pp)$ [19,34-42] and $b(\bar{p}p)$ [19,28,33,39,42-47]. The resulting parameters G_i in $mb^{1/2}$; b_i and α_i' in $(GeV/c)^{-2}$ are given in Table 1. The corresponding descriptions of σ_{tot} and the elastic slopes are agreed well with data. The froissaron intercept $(1+\Delta)$ used with $\Delta = 0.17$ was found in [13].

5 Inclusive cross section

With the parameters of Table 1 one can fit the inclusive spectra in the central region. The data on the rapidity distributions at $y = 0$ are extracted from [48-60] using the procedure of [13]. In adition, the assumption $d\sigma(\pi^-) = 0.9 d\sigma(c^-)$ is used. The inclusive spectra at non-zero values of y are taken from [49,52-56,60-66]. The restriction $|y| < 1.5$ is used during the fit procedure. In addition to the negatively charged particles we also fit the K_s production. The corresponding data can be found in [67], but because of the pauucity of antiproton data at low energies, we considered them as data for protons.

Apart from the parameters, normalization constants for different experiments should be determined as well. The data have to be re-calculated using a unique scale and then other parameters can be found. Such a procedure is rather difficult because sometimes the value of the total cross section used as a scale for a given data set is unknown. Therefore, one can use the simpler procedure: fit the scale factors for different data sets in a 20% interval. The parameters obtained in such a way are presented in Table 2. All G_i are in $mb^{1/2}$. The corresponding scale factors are given in Table 3. Their small variation is evidence of the quality of the procedure.

The energy dependence of $d\sigma/dy$ at $y = 0$ is shown in Fig.2 in comparison with the data for various reactions. At the highest energies the first term in (6) dominates. It gives us the bonus of a prediction for hadron production cross sections at the energies of future colliders (Table 4). The calculated rapidity distributions in the central region are in good agreement with data in a wide energy region, as shown in Fig.3-5.

6 Conclusions

One can see from the analysis presented above that DRD give a good description of inclusive spectra in the central region with the two-pole approximation for the Pomeron singularity, and do not with the one-pole one. The leading Pomeron singularity with intercept $\alpha_F = 1 + \Delta$ and $\Delta = 0.17$ is suitable for the inclusive π and K-meson yields as well as for σ_{tot} and the elastic slope.

It should be stressed that DRD give a universal power law behavior of rapidity distributions at $y = 0$ independently of the particle types. Consequently, for heavy particle production one can expect

$$\frac{d\sigma_Q}{dy}|_{y\simeq 0} \simeq A_Q s^{\Delta} \tag{9}$$

The overall normalization constant A_Q is dependent on the particle type and can not be determined in Regge theory. But as was mentioned in the introduction, the properties of the Pomeron singularity are connected closely to the small$-x$ behavior of the DIS structure function. For the considered case one can expect

$$f(x) = 1/x + \beta/x^{1+\Delta}, \tag{10}$$

where β determines the relative contributions of the leading Pomeron singularities (P and F).

Using (10) one can describe the energy behavior of the inclusive cross section in the central region for Ψ-particles. For large x we take the usual parametrization $f(x) \sim (1-x)^n$ with n determined by the quark counting rules. The result is presented in Fig.6. It would be interesting to verify the pure power law in the high energy region, e.g. at Tevatron and UNK colliders.

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Table 1 : Elastic amplitude parameters

G_F	G_P	G_R	$\bar{G}_R$
$0.69 \pm .07$	$1.55 \pm .11$	$2.50 \pm .76$	$5.86 \pm .95$
b_F	b_P	b_R	
$3.97 \pm .53$	$3.06 \pm .80$	$1.73 \pm .32$	
α'_F	α'_P	α'_R	
0.25	0.25	1.00	
Δ_F	Δ_P	Δ_R	
0.17	0.00	-0.5	

Table 2 : Double-reggeon amplitude parameters

	c^-	K_s
G_F	0.69	0.69
G_P	1.55	1.55
G_R	0.54 ± 0.02	$0.53 \pm .04$
$\bar{G}_R$	0.24 ± 0.02	$0.46 \pm .14$
A_{FF}	13.57 ± 1.43	$1.76 \pm .36$
A_{FP}	-9.66 ± 1.08	$-1.33 \pm .33$
A_{FR}	-48.51 ± 3.15	$-5.51 \pm .27$
A_{PP}	6.67 ± 1.00	$0.53 \pm .02$
A_{PR}	16.11 ± 2.81	$2.35 \pm .24$
A_{RR}	-72.9 ± 7.46	$-5.95 \pm .70$

Table 3 : Normalization coefficients

Ref.	Norm.	Ref.	Norm.
	$p+p\to c^-X$		$\bar{p}+p\to c^-X$
49	$1.0022\pm .018$	65	$0.8005\pm .035$
49	$1.0705\pm .020$	60	$0.9625\pm .017$
52	$1.0544\pm .017$	61	$0.9825\pm .023$
53	$0.9402\pm .021$	62	$1.0205\pm .020$
54	$1.0987\pm .021$	62	$1.0377\pm .023$
54	$0.9929\pm .017$	66	$0.9866\pm .018$
56	$1.0284\pm .015$		K_s-production
60	$0.9194\pm .014$	68	$1.0371\pm .078$
64	$0.8279\pm .019$	69	$0.8000\pm .248$

Table 4 : Calculated production cross sections $d\sigma/dy$ at $y=0$

	1.8 TeV FNAL	6 TeV UNK	18 TeV LHC	40 TeV SSC
$\sigma(c^-), mb$	115 ± 12	173 ± 19	251 ± 26	330 ± 35
$\sigma(K_s), mb$	11 ± 3	17 ± 5	24 ± 7	31 ± 10

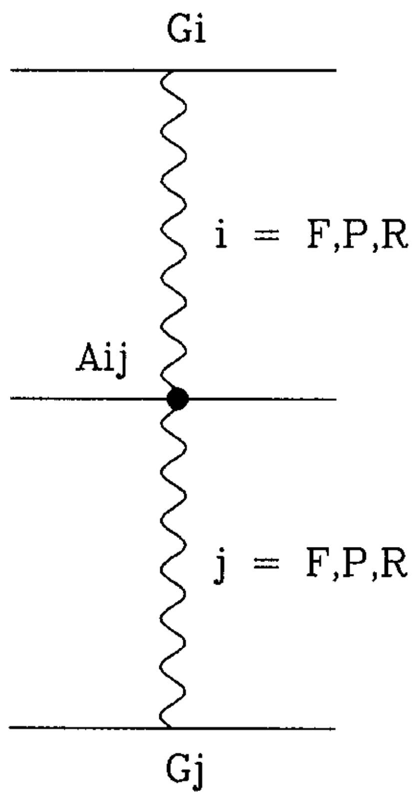

Fig.1. Double reggeon diagram

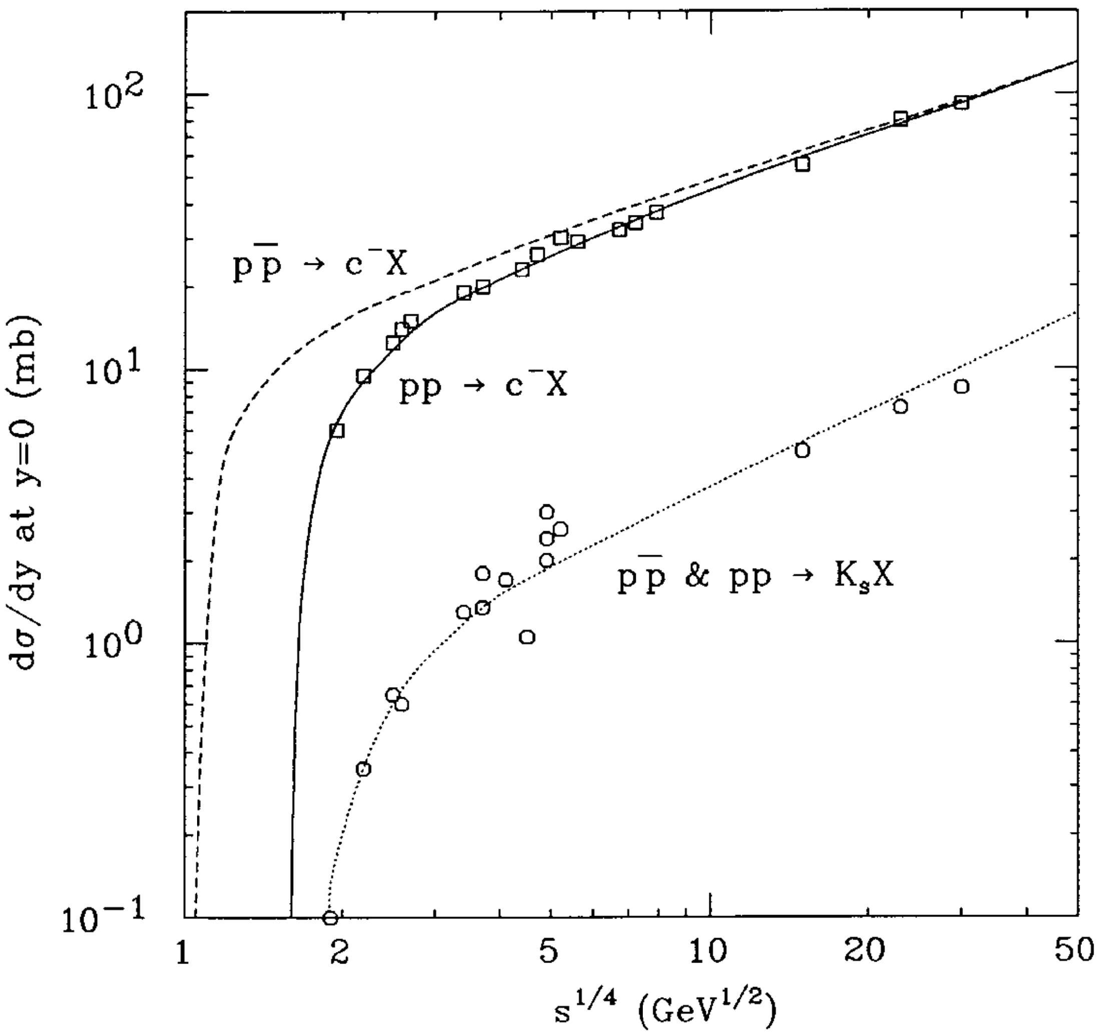

Fig.2. Energy dependence of inclusive spectra at y=0

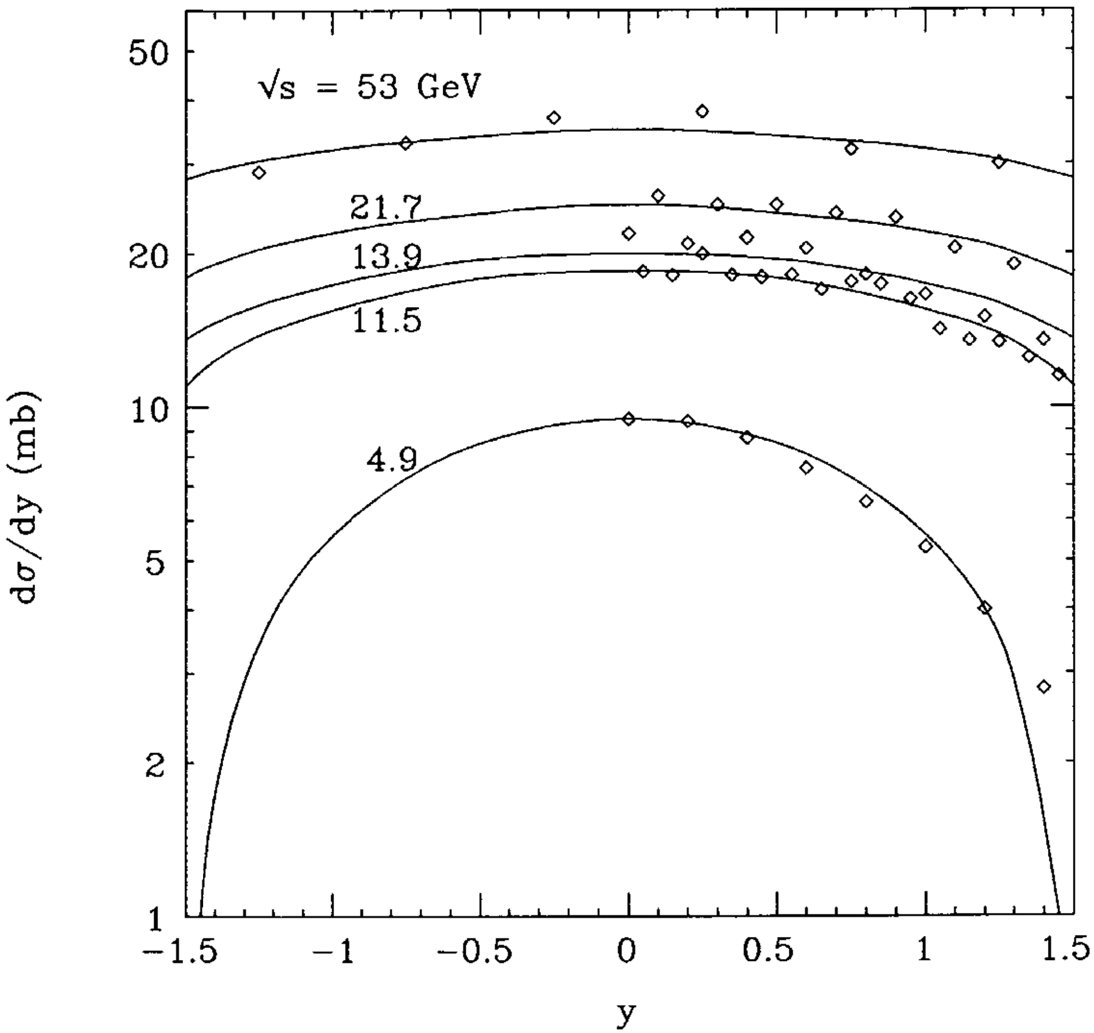

Fig.3. Inclusive spectra for reaction $pp \to c^{-}X$

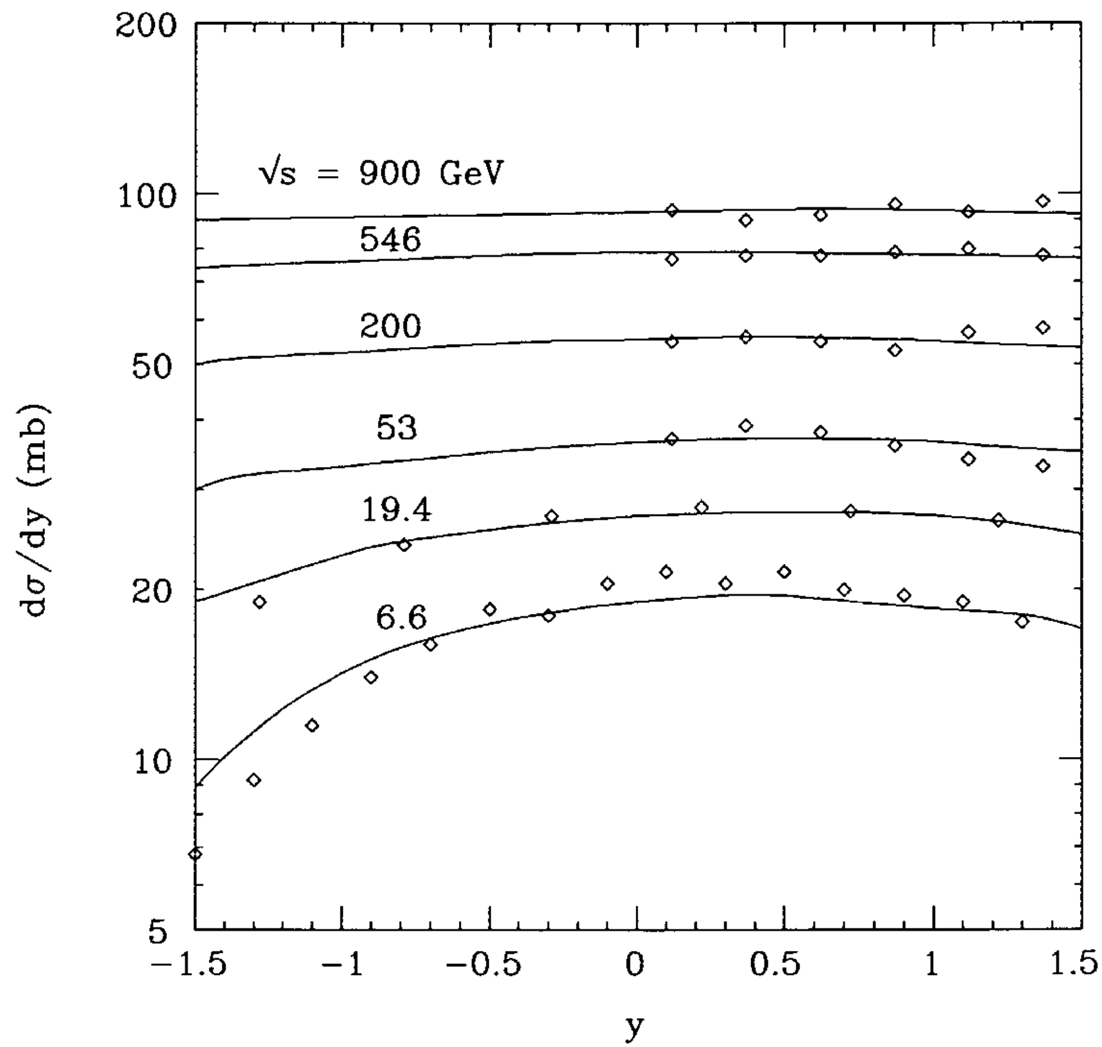

Fig.4. Inclusive spectra for reaction $p\bar{p} \to c^{-}X$

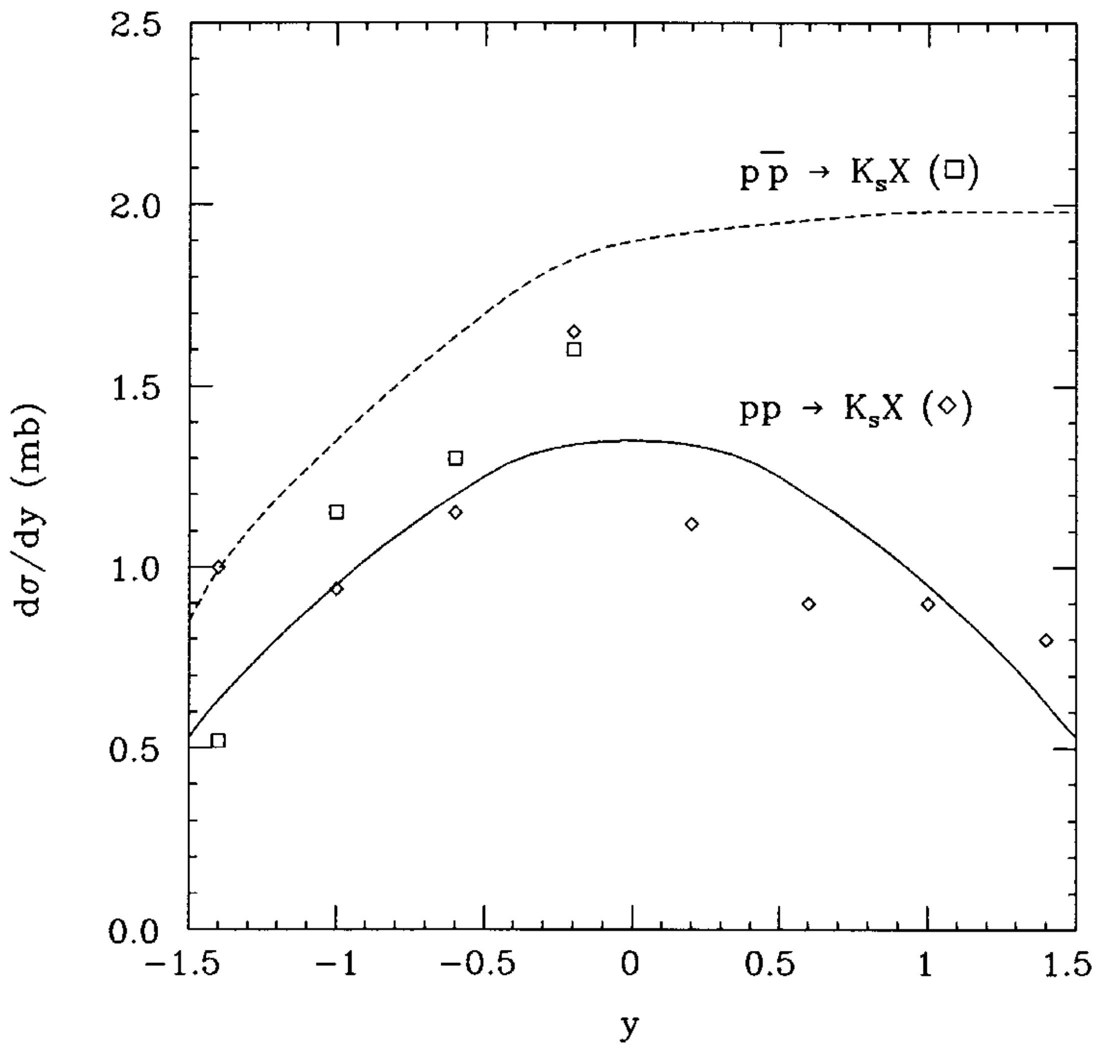

Fig.5. K_s inclusive spectra at $\sqrt{s}$ = 13.76 GeV

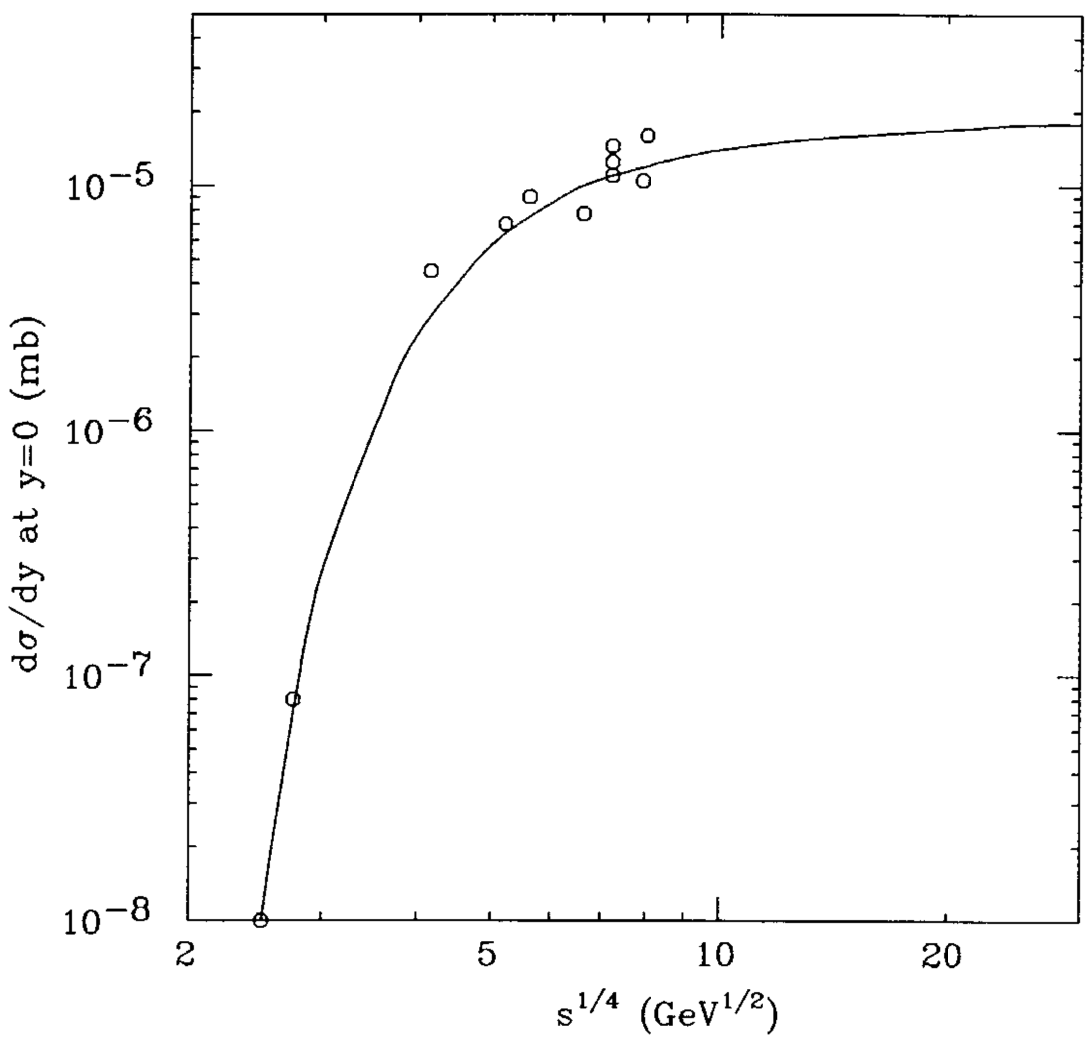

Fig.6. Inclusive cross section for pp → $J/\Psi X$ at y=0